Fundamental and Induced Biases in Technological Change in Central Canadian Agriculture

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A new procedure is developed to estimate innovation possibility frontiers and test for biases in technological change. Using data on four inputs (land, machinery, chemicals and labour) from central Canada (Ontario and Quebec) over the period 1926-1985, we find that the innovations possibilities frontier shifts neutrally over time. This is consistent with Ahmad's model of induced innovations, but is not consistent with de Janvry's application of Ahmad's model to the historical development of Argentine agriculture. Agricultural research in Canada has been conducted with the objective of developing cost minimizing technologies. Empirical support was found for this notion in the development of the innovation possibilities frontier.
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1.0 Introduction.

The spectacular growth of Canadian agricultural industry during the last century has been concomitant with that of the economy in general. There is little doubt that this growth has been driven in a large measure by the application of modern scientific methods to the agricultural industry in the development of new technologies and has been abetted by the development of a set of institutions that fosters this technological innovation.

One of the more interesting findings of the empirical literature on the growth of the agricultural industry is the impact of this growth on relative shares of factors of production. Several studies have shown that technological change in agriculture has been factor biased (for example Karagiannis and Furtan (1990) and Binswanger (1974) reported biased technological change in Canada and other countries). These biases have strongly labour and, to a lesser extent, land saving and capital using. However, some studies do not find biased technological change (e.g. Clark and Youngblood (1992)).

An appealing explanation of factor biases is the induced innovation hypothesis, originally developed by Ahmad (1966). According to this theory, a set of possible technologies is developed by research activities undertaken by the agricultural research community. The envelop of these technologies at a given level of output (normalized to be one unit) is called the innovation possibilities frontier (IPF). After the IPF has been developed, an observed technology is chosen by producers so as to minimize costs based on prevailing relative prices. This is the unit isoquant.

An assumption made by Ahmad (but not by de Janvry, (1977), who applies Ahmad's theories to agricultural development in Argentina) is that the IPF shifts inward over time in a neutral way.[1] If this is true, then all observed factor biases would be caused by induced technological change. If not, then at least some of the observed biases will result from fundamental biases in the manner in which the IPF shifts inwardly over time.

We develop a new method to estimate the IPF curve. In this way, one can test the hypothesis that this curve shifts neutrally and show how much of the observed bias in technological change is induced, and how much is due to a fundamental change in the IPF. We argue that the research community develops the IPF to minimize costs based on expected relative prices. We apply our methods to Central Canadian (Ontario and Quebec) agriculture for the years 1926-1985.

2.0 A Model of Induced Innovation.

Historically, the IIPF has developed in response to research activities undertaken by private and public institutions. In Canada, for example, research activities in agriculture have been mostly undertaken by universities, private firms and research stations funded by the federal government. One hypothesis is that research activities undertaken by research institutions is driven by a desire to minimize the expected costs of producers. In order to do this, the IPF should develop according to cost minimizing principles based on expected relative prices. Expected relative prices are the relevant prices because of the lag between when research is undertaken and when it becomes available to the agricultural community in terms of influencing the technology that the industry develops (which is based on cost minimizing principles using actual relative prices). For example,

[1]Neutrality is taken to mean that, if expected relative prices remain constant before and after the IPF shifts inward, factor intensities with remain constant.

if the lag between when research is undertaken and when it affects agriculture is five years, then the relevant set of expected prices that generate the IPF are expected relative prices today based on information available five years ago.

These ideas can be formalized using the duality theory of cost minimization. There is a two stage minimization problem associated with theory of induced innovation outlined in this study. In the first stage, the IPF function is developed based on cost minimizing principles using expected relative prices. In the second stage, a point on the cost function is selected based on cot minimizing principles using actual relative prices.

Fuss (1977) develops a model that can deliver empirical estimates of both the IPF function and the cost function that is consistent with the two stage processes described above. In the second stage, it is assumed that the cost function with the usual properties is given by the generalized

$$C_t(y_t, P_t) = y_t^{\alpha}\,[\sum\sum b_{ij}^{v}(p_{it}\,p_{jt})^{1/2}] \quad (1)$$

Leontief cost function, that is

where y_t is output, P_t is a vector of m input prices, $C_t(.)$ is cost, and α and b^v_{ij} , i=1,...,m, j=1,...m are parameters. Using Shephard's lemma, the conditional factor demand functions from (1) are given

$$X_{it} = y_t^{\alpha}\,[\sum_j b_{ij}^{v}(\frac{p_{jt}}{p_{it}})^{1/2}],\ j = 1,...m \quad (2)$$

by

where X_{it} is the ith factor. Dividing both sides of equation (2) by output yields

$$\frac{X_{it}}{y_t} = y_t^{\alpha-1} [\sum_j b_{ij}^v (\frac{p_{jt}}{p_{it}})^{1/2}]. \; j = 1,...m \quad (3)$$

If we assume that relationships (1) through (3) represent the long-run and that this is a constant cost industry, then constant returns to scale will characterize the industry.[2] In that case, α=1 and equation (3) becomes

$$\frac{X_{it}}{y_t} = \sum_j b_{ij}^v (\frac{p_{jt}}{p_{it}})^{1/2}. \; j = 1,...m \quad (4)$$

Equation (4) is particularly attractive from an estimation standpoint because it is linear in parameters.

The cost function given by equation (1) represents the technology that is developed from the IPF curve whereby individual producers minimize cost along an isoquant. This is a representation of the second stage optimization problem.

In the first stage optimization problem, the technology is developed based on expected relative prices. In the Fuss model, the first stage optimization problem takes the b^v_{ij}'s, which are fixed in the long run, as choice variables based on expected relative prices. That is

[2] The fact that equation (3) represents a long-run relationship seems to be a reasonable interpretation due to its contemporaneous nature and lack of dynamics, see Clark and Youngblood (1994).

$$b^{v}_{ijt} = \sum_{k}\sum_{l} a_{ij.kl} \frac{(p^{E}_{kt} p^{E}_{lt})^{1/4}}{(p^{E}_{it} p^{E}_{jt})^{1/4}} \quad (5)$$

where $a_{ij.kl}$, i=1,...m, j=1,...m, k=1,...m l=1,...m are parameters and p^{E}_{gt}, g=i,j,k,l is the expected price of factor g.[3] Fuss shows that, if the b^{v}_{ijt}'s are chosen according to equation (5) and the IPF technology satisfies symmetry and concavity, then costs are minimized over the IPF curve. Since the parameters of the cost function change over time due to research activities, then the relationship is called the very long run in the literature.

The discussion until now has taken place without consideration of technological change. To

$$a_{ii.iit} = c_{i0} + c_i t, i = 1,...m \quad (6)$$

account for fundamental technological change bias, consider the following equation

where t is time, and c_{i0} and c_i are parameters. If technological change is fundamentally biased then c_i in equation (6) is non-zero, with it being factor i saving (using) if $c_i < 0$ (> 0) (Chambers and Vasavada, (1983)). Of course, technological change is fundamentally factor neutral if c_i=0 in equation (6). If c_i=0 for all factors, then all technological change is induced and there are no fundamental factor biases. This provides the empirical basis for testing if factor biases are

[3]Equation (4) is a specialized version of the derivation of the b^{v}_{ij}'s given in Fuss to account for our assumptions regarding how research is undertaken to develop technologies. That is, we assume that research is undertaken with a specific year lag (ten years, see below) that impacts of the technology only in that time period. These assumptions imply that the discount factor and expected output in the derivation given in Fuss cancel in the derivation given here.

fundamental or induced using parametric restrictions.

What remains is to develop a model of neutral technological change in terms of the theory presented in this section. If technological change is neutral, then all technological change is induced and none is fundamental. Chambers (1988) shows that, if technological change is (Hicks) neutral, then a cost function can be written

$$C(y_t, P_t, t) = \lambda(t) C(y_t, P_t) \quad (7)$$

where $\lambda(t)$ is a decreasing function of time. In this research, we set $\lambda(t) = (1/\gamma)t$ where $\gamma > 0$ is a parameter.

3.0 Empirical Considerations:

The data we use to estimate the model incorporating induced technological change are taken from Karagiannis and Furtan (1990) and run from 1926-1985 for four inputs: land, machinery, fertilizer (including chemicals) and labour for the Central Canadian region of Canada (Ontario and Quebec).[4] Given a four input model with the minimum number of symmetry restrictions imposed to generate a full column rank design matrix leaves 166 parameters to be estimated. Obviously, this precludes the estimation of the cost function as a separate equation in the system due to the fact that the row rank (number of observations) of the design matrix must be greater than the column rank.

This leaves us with the estimation of the four conditional factor demand functions. The

[4]The data cannot be updated past 1985 because the output series ceased to be collected after that date.

number of free parameters that can be estimated in each separate equation is forty two per equation if the parameter of returns to scale (α) is allowed to be free across equations. The parameter of neutrality (γ) is not identified from the conditional factor demand functions but the lack of an independent estimate of this parameter will not affect any of the results given below as long as $\gamma > 0$, as required by theory. Therefore, to achieve full parameter identification, we set γ=1.

An issue that must be dealt with concerns the selection of the lag between when research is undertaken and when it affects the b^v_{ij} parameters. Several studies taken from the returns to research literature (e.g. Klein et al (1994)) assume a ten year lag. While a careful reading of this literature reveals that the choice of the ten year lag is somewhat arbitrary, the choice of any other seems even more arbitrary. Therefore, we choose a ten year lag as the time horizon between when research is undertaken and when it affects cost function parameters.

Given the ten year lag, the next consideration is what type of expectations generator to use

$$E_t\, P_{it+n} = P_{it} \,.\, i = 1,\ldots,m \quad (8)$$

for expected prices. We assume that economic agents have static expectations, that is

where E_t is the expectations operator. Alternatively, if all prices follow a random walk, then the rational expectation of price is the same as the static expectation of price and equation (8) and the expectations operator can be interpreted as conditional on information available at time t.

A final consideration involves the selection of an appropriate estimation technique. Phillips-Perron Z_τ tests were undertaken on all of the variables included in the model. The results of these tests are not shown but are available from the authors upon request. The results of the Phillips-Perron test indicated that unit root non-stationarity could not be rejected for 150 of the 160 variables using a significance level of 10%. Given the large number of regressors in the model and the large percentage of these where unit root non-stationarity could not be rejected, it seems reasonable to proceed assuming all of the data are characterized by unit root non-stationarity.

Since the data indicate that unit root non-stationarity is a reasonable approximation of the data, cointegration techniques need to be applied to the estimation. One advantage of such an approach is that the cointegrating relationship estimates the long run relationship that exists among variables (e.g. Engle and Granger (1987)). This interpretation is consistent with the theory described in the previous section.

Since four input demand functions must be estimated, a system of equations estimation technique such as Park and Ogaki's (1990) seemingly unrelated canonical cointegrating regression technique would be the most general approach to estimate the model. However, due to the large number of regressors included in the model, the relevant matrices that need to be inverted are not of full rank. Therefore, in this study, we estimate each separate equation using Park's single equation canonical cointegrating regression (CCR) technique. The CCR equations are stacked in the usual seemingly unrelated regression way using a diagonal covariance matrix, with the diagonal elements being the estimated long run variance for each equation. The estimated covariance matrix is used to estimate the parameters using GLS applied to the transformed data from the CCR estimates. If we assume that cross equation correlation among variables is zero and that each factor demand equation represents a separate cointegrating relationship, then the CCR methodology will deliver consistent and asymptotically normally distributed parameter estimates. This implies that parameters can be estimated and statistical inference applied using the CCR methodology.

4.0 Results.

Recall the assumption of long run constant returns to scale. This implies that $\alpha=1$ in equation (1) and the conditional factor demands are linear in parameters. Otherwise, the model is nonlinear. It would be desirable to conduct some type of statistical test for this hypothesis, however, the statistical theory of nonlinear models under the assumption of cointegration has, to our knowledge, not been developed. Furthermore, the large number of regressors included in the model requires that estimation methods conserve degrees of freedom.

Notice that, once a value of α has been selected, the model is linear. Therefore, a grid search method is used to search for the value of α that minimizes the residual sums of squares derived from the OLS estimates of each conditional factor demand. This minimizing value is compared to the residual sums of squares derived from the model imposing the restriction that $\alpha=1$. These two residuals sums of squares are then used to construct a standard f-value in order to test the hypothesis that $\alpha=1$. For the linear case, if it is assumed that all of the regessors are random walks and the error term for each equation is white noise and uncorrelated with any of the regressors, then regular f-statistics can be used to test hypotheses concerning the cointegrating vector (Hamilton, 1994). Violation of any of these assumptions will cause the estimated variance of the parameters to be too small and cause over-rejection of hypotheses using regular f- statistics (Phillips and Durlauf, 1988).

The results of testing for constant returns to scale using the methods described above are presented in Table 1. Long run constant returns are not rejected for land and labour using a 5% level of significance and not rejected for any of the conditional factor demand functions using a 1% level of significance. Since there is a likelihood of over rejection of hypotheses with the methods used to derive the tests, a 1% level of significance is probably reasonable. Therefore, we conclude that long-run constant returns is not rejected for these data. Results presented hereafter are with the restriction $\alpha=1$ imposed.

Tests for cointegration among the variables for the conditional factor demands are presented in Table 2. Park's (1992) superfluous variable addition test is used to test for cointegration using polynomial trends as superfluous regressors. The null hypothesis of cointegration is not rejected for any of the equations using a significance level of 5%. Therefore, we conclude that for all four factors demands, the CCR estimator is identifying cointegrating long run relationships among the variables.

Table 3 presents some tests of hypotheses and performance indicators associated with the estimated relationship. Foremost among the tests is that neutral technological change of the IPC function is not rejected by these data. In contrast, the model was estimated in standard generalized Leontief form (not shown, but available upon request) without including expected relative prices to identify the IPF curve. Using this system, neutral technological change was strongly rejected, indicating labour saving and machinery using technological change, although cointergation among the reduced system variables was rejected for all four factor demands. These results indicate that expected relative prices are important in explaining the long-run movements of factor demands and that the long run trends in these factor demands cannot be explained by trends in actual relative prices but are explained by expected relative prices. In other words, while there is evidence that there is strong biases in technological change, all of these biases are induced.

The other performance indicators presented above caution us to temper the conclusions of this study. For example, symmetry is strongly rejected by the data, indicating that the theory presented concerning the generation of the IPF as an optimization problem is called into question. The results of other performance measures of the estimated relationship are somewhat mixed. Although the estimated relationship performs fairly well in terms of monotonicity, it is marginal in terms of negativity and concavity.

Table 4 presents the estimated Morishima elasticities of substitution evaluated at the mean of the data where negativity holds. Examination of the eigenvalues of the matrix of second order partial derivatives indicated that the function is concave at this point. In general, all inputs are substitutes, and fairly high in absolute value when compared to other studies. Given that the cointegrating relationship estimates the long-run relationship among variables, high elasticities of substitution are consistent with l'Hopital's principle.

5.0 Conclusions.

In this study, a model is developed to directly estimate the parameters of the innovation possibilities frontier. A test of fundamental versus induced biased technological change is obtained and applied to Central Canadian agriculture. We find that all technological change is induced, or that the innovations possibilities frontier shifts neutrally over time. This is consistent with Ahmad's model of induced innovations, but is not consistent with de Janvry's application of Ahmad's model to the historical development of Argentine agriculture.

There is also evidence to suggest that the manner in which research is undertaken in Canada is consistent with expected cost minimizing behaviour on the part of researchers, or at least a research allocation policy on the part of funding agencies that encourages research designed to minimize expected costs. Empirical support was found for this notion in the development of the innovation possibilities frontier.

Nonetheless, our results need to be refined in several ways. The empirical model performed well in terms of monotonicity but only marginally well in terms of negativity and concavity. Symmetry was rejected. This could perhaps be due to the assumption of a ten year lag in the undertaking of research before it affects the prevailing technology, or the assumption of static price expectations. Certainly, more work needs to be undertaken on this topic before more definitive statements can be made concerning the historical development of modern agriculture in Canada.

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Table 1: Tests for Long-Run Constant Returns to Scale[a]

Factor Demand	Calculated F-value
Land	0.79
Machinery	9.15
Fertilizer and chemicals	6.18
Labour	1.12

[a]Critical F-Value: 5%, 5.12; 1%, 10.6;

Table 2: Park superfluous variable addition test statistics for Central Canadian conditional factor demand functions				
Superfluous regressors	Land	Machinery	Fertilizer	Labour
Quadratic trend	0.001 (0.96)	0.76 (0.38)	2.26 (0.13)	0.01 (0.92)
Quadratic and Cubic trend	0.209 (0.90)	1.76 (0.41)	2.73 (0.26)	0.53 (0.77)
Quadratic, cubic and quartic trend	0.273 (0.96)	1.77 (0.62)	2.74 (0.43)	0.54 (0.91)
Values in parentheses underneath statistics are significance levels.				

Table 3: Performance measures of estimated long-run cost function[a]				
Statistical tests		Other measures		
Test	Value		Number	Percent
		Monotonicity	49	96
Neutral Tech. Change	2.73 (0.60)	Negativity	14	27
Symmetry	1930.07 (0.00)	Concavity	8	16
[a] Values in parentheses underneath test statistics are significance levels.				

Table 4: Long-run Morishima elasticities of substitution evaluated at the mean of data where negativity holds				
	Factor			
Price	Land	Machinery	Fertilizer	Labour
Land	0	6.85	5.92	5.55
Machinery	2.88	0	0.99	3.44
Fertilizer	0.49	0.03	0	1.01
Labour	7.09	9.46	8.20	0